



The Municipal Water Quality Investigations Program

*Summary and Findings from Data Collected
August 1998 through September 2001*

July 2003

State of California
The Resources Agency
Department of Water Resources
DIVISION OF ENVIRONMENTAL SERVICES

State of California
The Resources Agency
Department of Water Resources
Division of Environmental Services

The Municipal Water Quality Investigations Program Summary and Findings from Data Collected August 1998 through September 2001



July 2003

Gray Davis
Governor
State of California

Mary D. Nichols
Secretary of Resources
The Resources Agency

Michael J. Spear
Interim Director
Department of Water Resources

If you need this publication in an alternate form, contact the Municipal Water Quality Investigations Program at the Division of Environmental Services or the Department's Office of Water Education at 1-800-272-8869.

Foreword

Water in the Sacramento-San Joaquin Delta (the Delta) is a major source of drinking water for two-thirds of California's population. Delta waters originate mostly from precipitation in the Sierra, the Cascade Range, and the watersheds of the Sacramento and San Joaquin valleys. Water from the Sierra and in the storage facilities outside the Delta are of high quality. When water traverses the complex Delta to diversion points, drinking water quality degrades.

Municipal Water Quality Investigations (MWQI), a program within the Division of Environmental Services of the California Department of Water Resources, is the only state program whose primary mission is to investigate and protect Delta drinking water quality. Since 1983, MWQI has been conducting comprehensive and systematic monitoring at various points near and within the Delta along the water transport path to the diversion locations.

This report summarizes and interprets MWQI monitoring data collected from August 1998 through September 2001 from 14 MWQI sampling stations. Major water quality constituents examined in this report include organic carbon, bromide, salinity, regulated organic and inorganic constituents in drinking water, and a few unregulated constituents of current interest. In addition to presenting the basic summary statistics, this report also discusses seasonal and spatial patterns, differences among stations, and sources of some constituents.

This and other MWQI reports are available online at the MWQI web site: <http://www.wq.water.ca.gov/mwq/index.htm>. For further information about the MWQI program, please visit its website or contact Richard S. Breuer, Program Manager, (916) 651-9687, or send your request to: P.O. Box 942836, Sacramento, CA 94236-0001.



Barbara McDonnell
Chief, Division of Environmental Services

State of California
Gray Davis, Governor

The Resources Agency
Mary D. Nichols, Secretary for Resources

Department of Water Resources
Michael J. Spear, Interim Director

L. Lucinda Chipponeri
Deputy Director

Peggy Bernardy
Chief Counsel

Stephen Verigin
Acting Chief Deputy Director

Jonas Minton
Deputy Director

Peter Garris
Deputy Director

Vernon T. Glover
Deputy Director

Division of Environmental Services
Barbara McDonnell, Chief

Office of Water Quality
Phil Wendt, Chief

Municipal Water Quality Program Branch
Dan Otis, Chief

Prepared under the direction of
Richard S. Breuer, Chief
Municipal Water Quality Investigations

Prepared by
Fengmao Guo, Project Leader
Jaclyn Pimental

With assistance from
William J. McCune
Murage Ngatia

Editorial review, graphics, and report production
Brenda Main, Supervisor of Technical Publications
Marilee Talley, Lead Editor
Joanne Pierce, Graphics Editor
Alice Dyer, Cover Design

**Office of Water Quality
Municipal Water Quality Program Branch**

Quality Assurance/Quality Control

Bruce Agee, Chief

Murage Ngatia, Environmental Scientist

Jaclyn Pimental, Environmental Scientist

Field Support

David Gonzalez, Chief

Walt Lambert, WR Engineering Associate

Steven San Julian, Environmental Scientist

**Office of Water Quality
Bryte Chemical Laboratory**

William Nickels, Chief

Sid Fong, Public Health Chemist III (Supervisor)

Pritam Thind, Public Health Chemist III

Richard Hernandez, Public Health Chemist II

Josie Quiambao, Public Health Chemist II

Mark Betencourt, Public Health Chemist I

Maritza Pineda, Public Health Chemist I

Mercedes Tecson, Public Health Chemist I

David Nishimura, Public Health Chemist I

Elaine Chan, Laboratory Assistant

Marilyn Toomey, Laboratory Assistant

Shelly Bains-Jordan, Business Services Assistant

Acknowledgments

The authors thank our colleagues Mr. Bruce Agee, Mr. Rich Breuer, Ms. Carol DiGiorgio, Mr. David Gonzalez, Mr. Marvin Jung, and Mr. William McCune and also Mr. Richard Woodard of the State Water Contractors (SWC) for reviewing and providing valuable comments. Special thanks are extended to Dr. Paul Hutton of the SWC and Ms. Lisa Holm and Mr. Richard Denton for their feedback. We thank Mr. William McCune for his camaraderie and sharing his rich experience with us on numerous occasions. Special thanks to Mr. Bruce Agee for answering many database questions and resolving data retrieval problems, to Mr. William Nickels and Mr. Sid Fong for responding to many questions on chemical analysis and data quality, to Mr. Mike Zanolli for discussing Chapter 4 with us, and to Mr. Barry Montoya for clarifications on data from Banks and Delta-Mendota Canal stations. We are grateful to Mr. Michael McGinnis and Ms. Iris Yamagata of DWR's San Joaquin District for providing data for inclusion in this report. The authors are particularly grateful to Ms. Marilee Talley for her excellent editorial work, which helps improve the readability of this report. Special thanks are also extended to Ms. Joanne Pierce for creating the maps in this report. We thank Ms. Brenda Main for her enthusiastic support of this project. The MWQI program gratefully acknowledges support of the following State Water Project contractors:

Alameda County Flood Control and Water Conservation District Zone 7
Alameda County Water District
Antelope Valley-East Kern Water Agency
Casitas Municipal Water District
Castaic Lake Water Agency
Central Coast Water Authority
City of Yuba City
Coachella Valley Water District
Contra Costa Water District
County of Butte
County of Kings
Crestline-Lake Arrowhead Water Agency
Desert Water Agency
Dudley Ridge Water District
Empire-West Side Irrigation District
Kern County Water Agency
Littlerock Creek Irrigation District
Metropolitan Water District of Southern California
Mojave Water Agency
Napa County Flood Control and Water Conservation District
Oak Flat Water District
Palmdale Water District
Plumas County Flood Control and Water Conservation District
San Bernardino Valley Municipal Water District
San Gabriel Valley Municipal Water District
San Geronio Pass Water Agency
San Luis Obispo County Flood Control and Water Conservation District
Santa Clara Valley Water District
Solano County Water Agency
Tulare Lake Basin Water Storage District

Content

| | |
|--|-----|
| Foreword | iii |
| Organization..... | v |
| Acknowledgments..... | vii |
| Executive Summary | 1 |
| Purpose..... | 1 |
| Background | 1 |
| Scope of Report..... | 2 |
| Summary of Findings..... | 3 |
| Organic Carbon | 3 |
| Bromide..... | 4 |
| Salinity | 5 |
| Other Constituents..... | 5 |
| Recommendations..... | 5 |
| Chapter 1 Introduction | 15 |
| Overview | 15 |
| Monitoring Stations..... | 16 |
| Definitions of Terms | 17 |
| Chapter 2 Data Collection and Analysis | 23 |
| Selection of Constituents | 23 |
| Sample Collection | 23 |
| Laboratory Analysis..... | 24 |
| Data Quality | 25 |
| Statistical Analysis..... | 25 |
| Descriptive Plots | 25 |
| Descriptive Statistics..... | 26 |
| Nonparametric Statistical Methods | 26 |
| Chapter 3 Watershed and Delta Hydrology | 33 |
| Precipitation | 33 |
| Runoff Index | 34 |
| Delta Outflows | 34 |
| Chapter 4 Organic Carbon | 43 |
| Overview | 43 |
| Ranges and Seasonality of Organic Carbon at Individual Stations..... | 44 |
| American River | 44 |
| Sacramento River | 44 |
| San Joaquin River | 46 |
| Delta Channel Stations..... | 47 |
| Ranges and Seasonality of Organic Carbon at Diversion Stations | 48 |
| Banks Pumping Plant | 48 |
| Delta-Mendota Canal | 48 |
| Contra Costa Pumping Plant | 49 |

| | |
|--|---------|
| Organic Carbon Differences among Stations..... | 49 |
| Sacramento River Stations | 49 |
| San Joaquin River Stations..... | 50 |
| Delta Channel Stations..... | 51 |
| Sacramento River vs. San Joaquin River | 51 |
| Organic Carbon Differences in Diversions Waters..... | 51 |
| Sources of Organic Carbon in Delta Waters | 52 |
| Agricultural Drainage Returns | 52 |
| Urban Sources | 52 |
| UVA ₂₅₄ and DOC Relationships | 54 |
| UVA ₂₅₄ and Organic Carbon Aromaticity..... | 54 |
| Ranges of UVA ₂₅₄ in Delta Waters | 54 |
| Relationships Between UVA ₂₅₄ and DOC in Delta Waters | 55 |
| Specific UVA ₂₅₄ and DOC | 55 |
| DBP Formation Potential of Delta Waters..... | 56 |
| DBPFP at Delta Stations | 56 |
| DBPFP at Diversion Stations | 57 |
| DBPFP Predictors | 57 |
| TOC and DOC Relationships..... | 58 |
| Chapter 5 Bromide..... | 89 |
| Overview | 89 |
| Seasonal Variations and Differences among Stations..... | 90 |
| American River WTP and Sacramento River Stations | 90 |
| San Joaquin River Stations..... | 90 |
| Channel Stations | 91 |
| Diversion Stations | 92 |
| Sources of Bromide in Delta Waters..... | 92 |
| Seawater Influence | 92 |
| Recirculation of Bromide within the San Joaquin Valley | 93 |
| Bromide from Delta Islands | 93 |
| Urban Drainage | 94 |
| The Relationship between Bromide and Chloride in Delta Waters | 94 |
| Chapter 6 Electrical Conductivity and Salinity..... | 107 |
| General Relationships between EC and TDS in Delta Waters..... | 107 |
| Ranges, Seasonality, and Differences among Stations | 107 |
| American River at the Fairbairn WTP Intake | 107 |
| Sacramento River Stations | 108 |
| San Joaquin River Stations..... | 109 |
| Channel Stations | 109 |
| Diversion Stations | 110 |
| Chloride and Sulfate..... | 110 |
| Relationships Between EC and Major Cations | 112 |
| Factors that Affect EC and Salinity in Delta Waters | 113 |
| Seawater Influence | 113 |
| In-Delta Agricultural Drainage | 114 |
| Agricultural Drainage to the Sacramento River | 114 |
| Agricultural Drainage to the San Joaquin River | 115 |
| Urban Drainage in and near the Delta..... | 116 |

| | |
|---|-----|
| Chapter 7 pH, Alkalinity, Hardness, and Turbidity | 141 |
| pH | 141 |
| Alkalinity | 141 |
| Hardness..... | 142 |
| Turbidity | 142 |
| Chapter 8 Other Water Quality Constituents | 151 |
| Constituents Affecting Taste, Odor, and Appearance..... | 151 |
| Methyl Tertiary-Butyl Ether | 151 |
| Metallic Constituents | 152 |
| Constituents Affecting Human Health | 152 |
| Boron..... | 153 |
| Nutrients..... | 154 |
| Chapter 9 Data Quality Review | 165 |
| Overview | 165 |
| Field Procedures Quality Control | 165 |
| Field Duplicates | 165 |
| Field Blanks | 165 |
| Internal Quality Controls | 166 |
| Sample Holding Times..... | 166 |
| Method Blanks | 166 |
| Laboratory Control Samples | 166 |
| Matrix Spike Recovery | 167 |
| Matrix Spike Duplicates..... | 167 |
| Sample Duplicates..... | 167 |
| References..... | |
| Literature cited | 193 |
| Personal communications..... | 194 |
| Glossary | 195 |
| Metric Conversion Factors..... | 199 |

Tables

| | |
|---|-----|
| Table A Inorganic and miscellaneous constituents | 7 |
| Table 1-1 MWQI monitoring stations, 1998-2001 | 19 |
| Table 2-1 MWQI water sample collection and preservation | 27 |
| Table 2-2 Analytical methods and reporting limits for included constituents | 29 |
| Table 3-1 Summary of daily precipitation (in inches) at six weather stations..... | 37 |
| Table 3-2 Summary of monthly precipitation (in inches) at six weather stations..... | 37 |
| Table 3-3 Hydrologic index classification based on measured unimpaired runoff at selected rivers | 38 |
| Table 4-1 Summary of organic carbon at 14 MWQI stations (mg/L)..... | 59 |
| Table 4-2 Sample distribution and statistics of UVA ₂₅₄ and DOC during the reporting period | 61 |
| Table 4-3 Disinfection byproduct formation potential in Delta waters | 62 |
| Table 4-4 Total disinfection byproduct formation potential at two diversion stations | 62 |
| Table 5-1 Summary of bromide at 14 MWQI stations (mg/L) | 97 |
| Table 6-1 Summary of TDS/EC ratios at 14 MWQI stations..... | 117 |
| Table 6-2 Summary of electrical conductivity at 14 MWQI stations ($\mu\text{S}/\text{cm}$) | 118 |
| Table 6-3 Summary of statistics for total dissolved solids (mg/L) | 119 |
| Table 6-4 Chloride and sulfate at 14 MWQI monitoring stations (mg/L) .. | 120 |
| Table 6-5 Summary of sodium, calcium, and magnesium at 14 MWQI monitoring stations | 121 |
| Table 6-6 Electrical conductivity at stations on the San Joaquin River and its major tributaries ($\mu\text{S}/\text{cm}$) | 122 |
| Table 7-1 Summary of pH at 14 MWQI monitoring stations | 145 |
| Table 7-2 Summary of alkalinity at 14 MWQI monitoring stations..... | 146 |
| Table 7-3 Summary of hardness at 14 MWQI monitoring stations..... | 147 |
| Table 7-4 Summary of turbidity at 14 MWQI monitoring stations..... | 148 |
| Table 8-1 Summary of MTBE at 14 MWQI monitoring stations | 157 |
| Table 8-2 Summary of data for metallic constituents | 158 |
| Table 8-3 Summary of regulated constituents in drinking water having federal and State primary MCLs | 159 |
| Table 8-4 Summary of boron at MWQI stations..... | 160 |
| Table 8-5 Summary of nitrate at 14 MWQI stations | 161 |
| Table 8-6 Summary of nutrient data at the Banks Pumping Plant..... | 161 |
| Table 9-1 Field duplicates..... | 169 |
| Table 9-2 Total internal QC batches grouped by analyte | 171 |
| Table 9-3 Holding time exceedances | 174 |
| Table 9-4 Method blank exceedances | 175 |
| Table 9-5 Number of batches with method blank exceedances | 175 |
| Table 9-6 Environmental samples associated with method blank exceedances | 176 |
| Table 9-7 Matrix spike recovery exceedances | 179 |
| Table 9-8 Frequency of QC batches with matrix spike recovery exceedances | 181 |
| Table 9-9 Samples with matrix spike recovery exceedances..... | 182 |
| Table 9-10 Matrix spike duplicate exceedances | 188 |

| | |
|--|-----|
| Table 9-11 Number of matrix spike duplicate recovery exceedances | 188 |
| Table 9-12 Samples with matrix spike duplicate exceedances | 188 |
| Table 9-13 Sample duplicate exceedances..... | 189 |
| Table 9-14 Number of sample duplicate exceedances..... | 189 |
| Table 9-15 Samples with sample duplicate exceedances..... | 190 |

Figures

| | |
|--|-----|
| Figure A Total organic carbon: Range, median (mg/L)..... | 9 |
| Figure B Bromide: Range, median (mg/L) | 11 |
| Figure C Electrical conductivity: Range, median ($\mu\text{S}/\text{cm}$) | 13 |
| Figure 1-1 MWQI monitoring stations, 1998–2001 | 21 |
| Figure 3-1 Location of selected weather stations (map) | 39 |
| Figure 3-2 Cumulated monthly precipitation (in inches) at six weather stations..... | 41 |
| Figure 3-3 Daily outflows at three Delta locations | 42 |
| Figure 4-1 Monitoring stations near the City of Sacramento (map) | 63 |
| Figure 4-2 Organic carbon at the American River and West Sacramento WTP Intake..... | 65 |
| Figure 4-3 Organic carbon at Hood and Mallard Island stations | 66 |
| Figure 4-4 Organic carbon at two San Joaquin River stations..... | 67 |
| Figure 4-5 Organic carbon at two Old River stations | 68 |
| Figure 4-6 Organic carbon at three Delta diversion stations..... | 69 |
| Figure 4-7 Monthly TOC at three stations sampled at the same time interval (Loess smoothing parameter = 0.2) | 70 |
| Figure 4-8 TOC at Vernalis and Highway 4 | 71 |
| Figure 4-9 Monthly TOC at two Old River stations (Loess smoothing parameter = 0.2)..... | 72 |
| Figure 4-10 TOC: Sacramento River at Hood vs. San Joaquin River near Vernalis | 73 |
| Figure 4-11 Monthly TOC at three Delta diversion stations (Loess smoothing parameter = 0.2) | 74 |
| Figure 4-12 Agricultural drainage returns (map)..... | 75 |
| Figure 4-13 Organic carbon at two agricultural drainage stations | 77 |
| Figure 4-14 Changes in organic carbon in the Old River in response to agricultural drainage returns (Loess smoothing parameter = 0.2) | 78 |
| Figure 4-15 Organic carbon at the Natomas East Main Drainage Canal | 79 |
| Figure 4-16 Organic carbon sources in the City of Stockton (map) | 81 |
| Figure 4-17 The relationship between UVA_{254} and DOC | 83 |
| Figure 4-18 UVA_{254} and DOC relationships at low UVA_{254} ranges | 84 |
| Figure 4-19 The relationship between SUVA_{254} and DOC..... | 85 |
| Figure 4-20 Disinfection byproduct formation potential at two Delta diversion stations | 86 |
| Figure 4-21 Disinfection byproduct formation potential, organic carbon, and SUVA_{254} relationships | 87 |
| Figure 4-22 Relationship between TOC by two different methods and DOC in Delta source waters | 88 |
| Figure 5-1 Bromide at two Sacramento River stations | 99 |
| Figure 5-2 Bromide at two San Joaquin River stations..... | 100 |
| Figure 5-3 Monthly bromide concentrations at two Old River stations..... | 100 |
| Figure 5-4 Bromide at three diversion stations | 101 |
| Figure 5-5 Bromide concentrations at the Mallard Island station..... | 101 |

| | |
|---|-----|
| Figure 5-6 Bromide at two Delta agricultural pumping stations..... | 102 |
| Figure 5-7 Bromide at the Natomas East Main Drainage Canal..... | 103 |
| Figure 5-8 Bromide and chloride relationship at three stations | 104 |
| Figure 5-9 The relationship between bromide and chloride at 10 stations..... | 105 |
| Figure 6-1 Relationship between EC and TDS at 14 MWQI stations | 123 |
| Figure 6-2 Monthly EC and TDS at the American River WTP Intake | 124 |
| Figure 6-3 Monthly EC and TDS at the West Sacramento WTP Intake..... | 124 |
| Figure 6-4 Weekly EC and TDS at the Hood station (Loess smoothing parameter = 0.05)..... | 125 |
| Figure 6-5 Weekly EC and TDS at San Joaquin River near Vernalis (Loess smoothing parameter = 0.05)..... | 125 |
| Figure 6-6 Monthly EC and TDS at the San Joaquin River at Highway 4 | 126 |
| Figure 6-7 Monthly EC and TDS at Old River at Station 9..... | 126 |
| Figure 6-8 Monthly EC and TDS at the Bacon Island Station on Old River .. | 127 |
| Figure 6-9 Monthly EC and TDS at three Delta diversion stations | 128 |
| Figure 6-10 EC, chloride, and sulfate relationships..... | 129 |
| Figure 6-11 Relationships between EC and major cations at 14 MWQI stations..... | 130 |
| Figure 6-12 Seawater influence in the Delta, 1921–1943 (map) | 131 |
| Figure 6-13 Monthly EC and TDS at the Mallard Island station | 133 |
| Figure 6-14 Monthly EC and TDS at the agricultural pumping plants at Bacon and Twitchell islands..... | 134 |
| Figure 6-15 Effects of rice drainage on EC at Greenes Landing | 135 |
| Figure 6-16 Stations in the San Joaquin River watershed from Delta-Mendota Canal to Vernalis (map) | 137 |
| Figure 6-17 EC and TDS at the Natomas East Main Drainage Canal station..... | 139 |
| Figure 7-1 Weekly turbidity at Hood and Vernalis stations | 149 |
| Figure 7-2 Monthly turbidity at three diversion stations | 149 |
| Figure 8-1 Nitrate at three diversion stations and two river stations | 163 |
| Figure 8-2 Nutrients at the Banks Pumping Plant Station | 164 |

Appendices

| | |
|---|------|
| Appendix A Method for Conversion TOC by Combustion to TOC by Oxidation | back |
| Background | A-1 |
| Approach..... | A-1 |
| Data Conversion..... | A-3 |
| Table A-1 Summary of converted TOC by combustion at 14 stations | A-5 |
| Figure A-1 Sample distribution by station and by month | A-7 |
| Figure A-2 TOC (combustion) vs. TOC (oxidation): Data clusters and regression equations for conversion | A-8 |
| Appendix B Report and Data in Electronic Format..... | back |